US010399683B2

(12) **United States Patent**
Behrens et al.

(10) **Patent No.: US 10,399,683 B2**
(45) **Date of Patent: Sep. 3, 2019**

(54) **THERMAL MANAGEMENT SYSTEMS AND METHODS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 268 days.

(21) Appl. No.: **15/044,523**

(22) Filed: **Feb. 16, 2016**

(65) **Prior Publication Data**

US 2017/0233082 A1 Aug. 17, 2017

(51) **Int. Cl.**

B64D 13/06	(2006.01)
B64D 37/34	(2006.01)
F02C 6/08	(2006.01)

(52) **U.S. Cl.**

CPC ***B64D 13/06*** (2013.01); ***B64D 37/34*** (2013.01); *B64D 2013/064* (2013.01); *B64D 2013/0618* (2013.01); *B64D 2013/0648* (2013.01); *B64D 2013/0674* (2013.01); *F02C 6/08* (2013.01); *Y02T 50/56* (2013.01)

(58) **Field of Classification Search**

CPC .. B64D 13/06; B64D 37/34; B64D 2013/064; B64D 2013/0648; B64D 2013/0674; F02C 6/08

See application file for complete search history.

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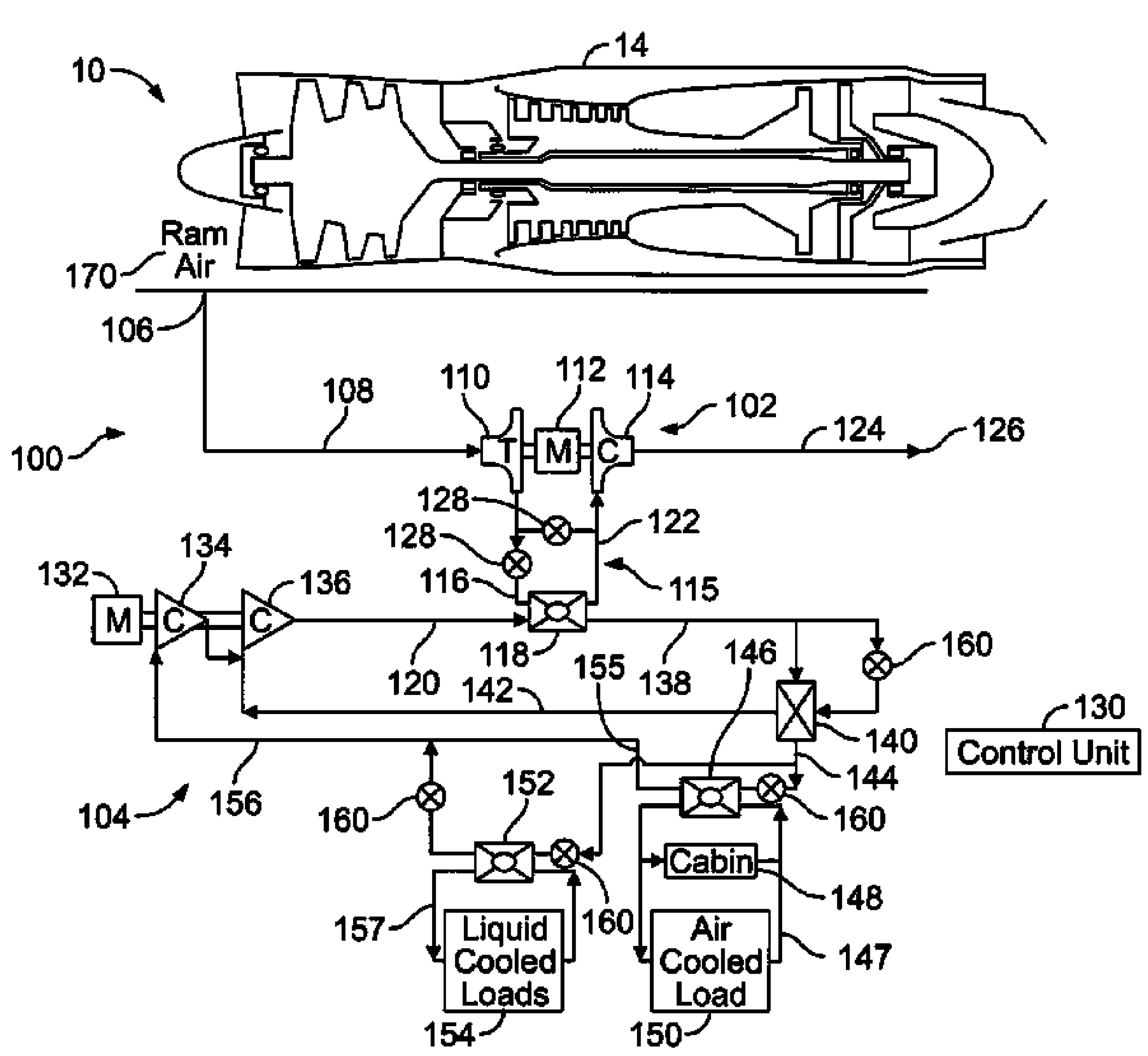
(57) **ABSTRACT**

A thermal management system includes at least one vapor control system (VCS) that is configured to cool portions of the vehicle. The VCS circulates a fluid therethrough to cool the portions of the vehicle through heat exchange. At least one reverse air cycle machine (RACM) couples to VCS through a first heat exchanger. The RACM is configured to receive ram air. The RACM expands the ram air. Heat from the fluid circulating through the VCS is transferred to the expanded ram air through the first heat exchanger.

20 Claims, 6 Drawing Sheets



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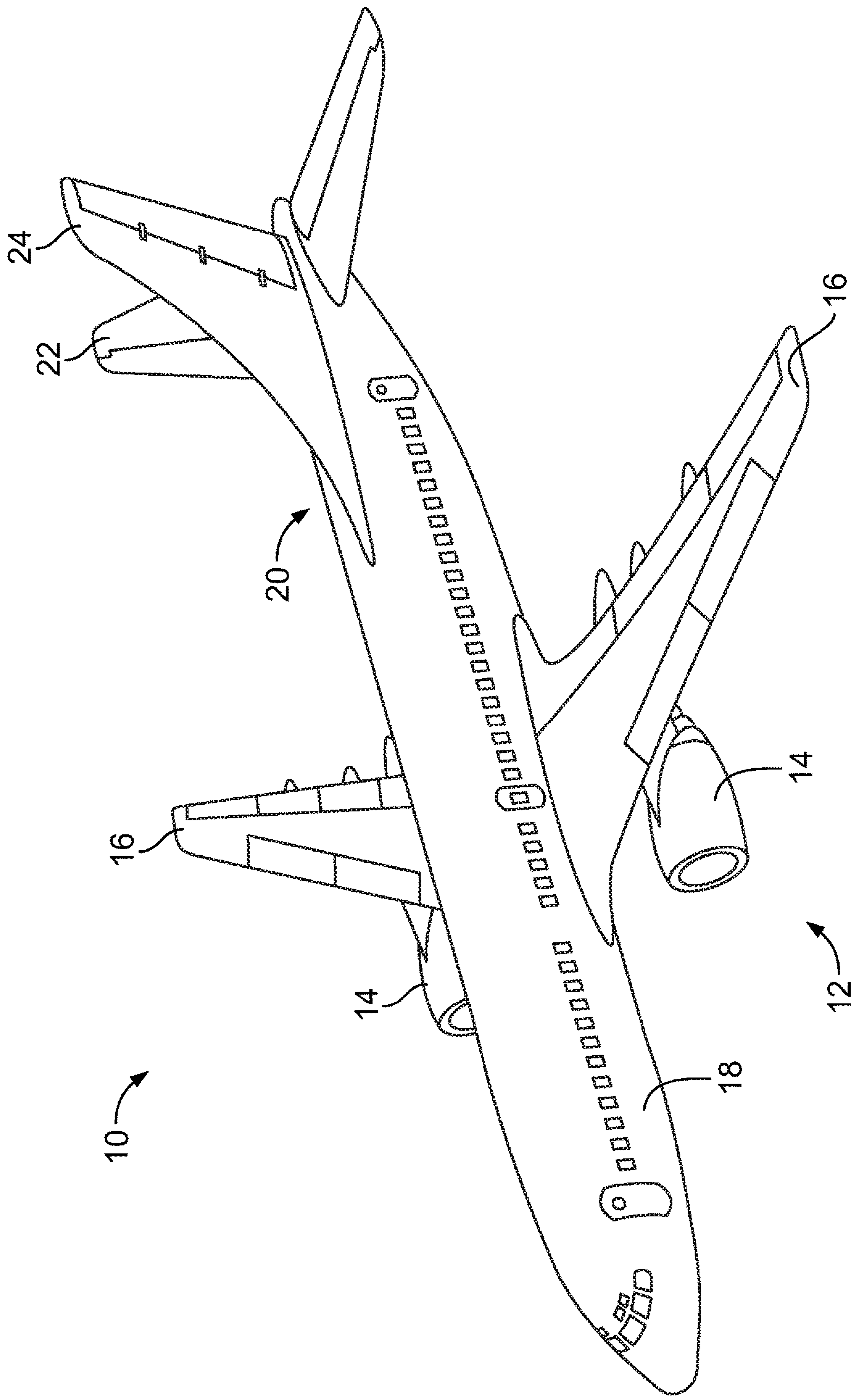


FIG. 1

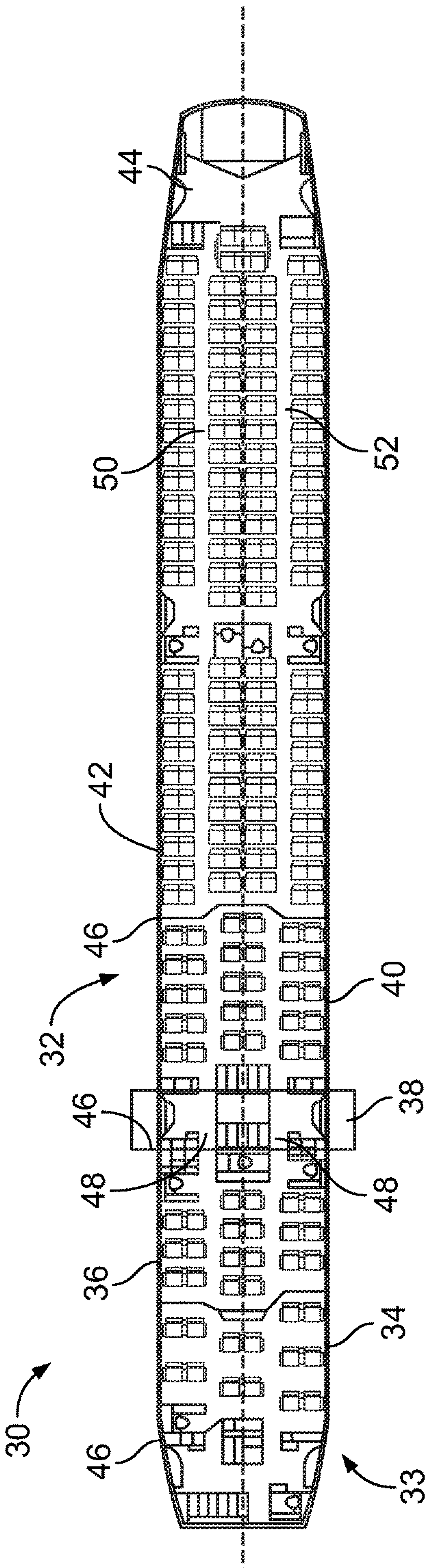


FIG. 2A

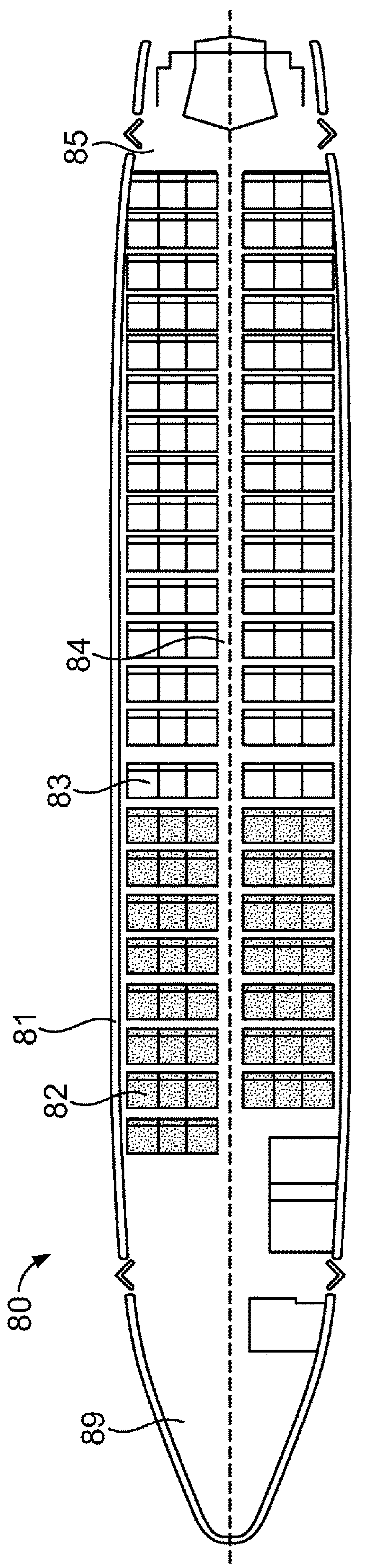


FIG. 2B

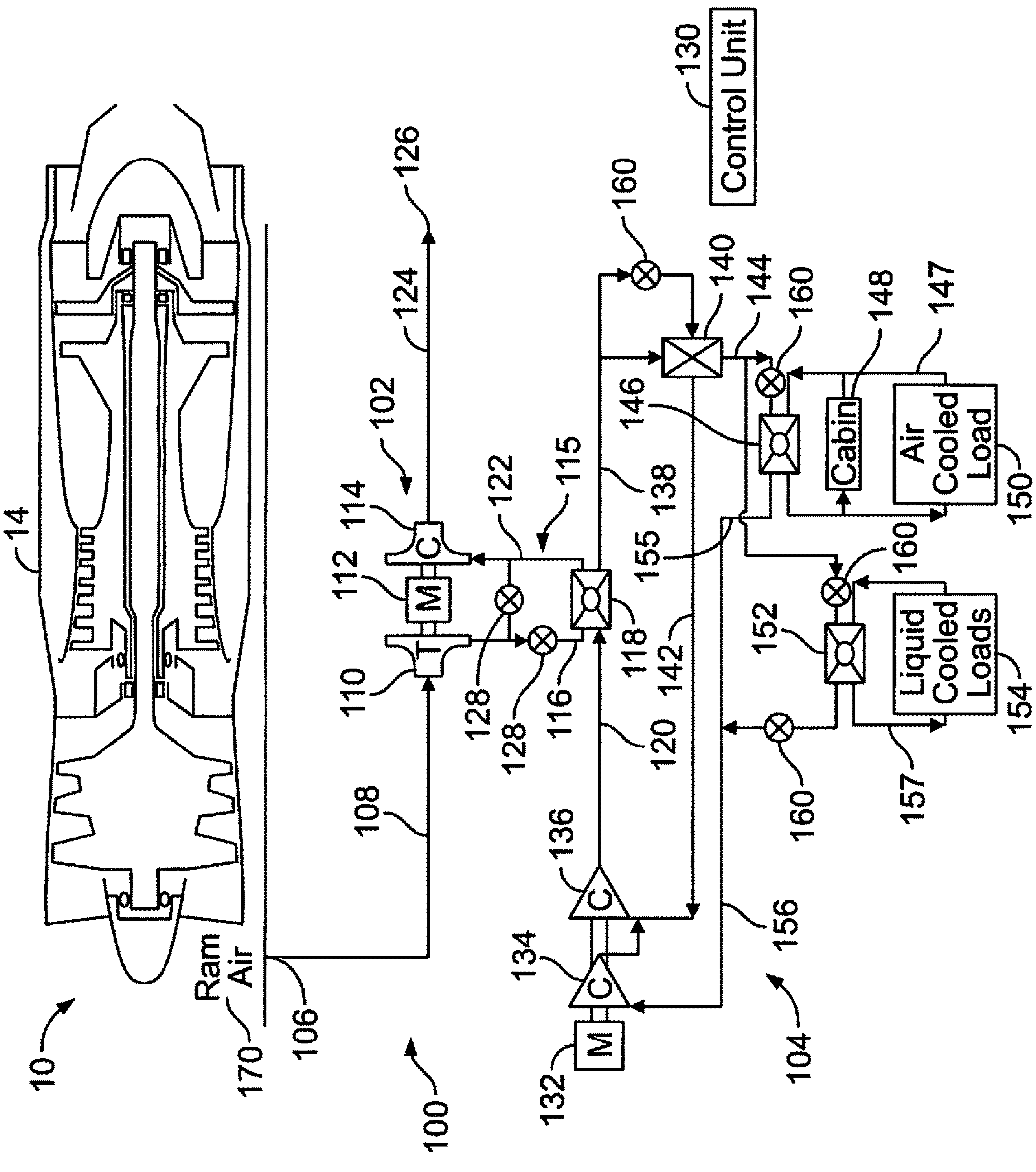

Ram Air
Control Unit
Cabin
Air Cooled Load
Liquid Cooled Loads

FIG. 3

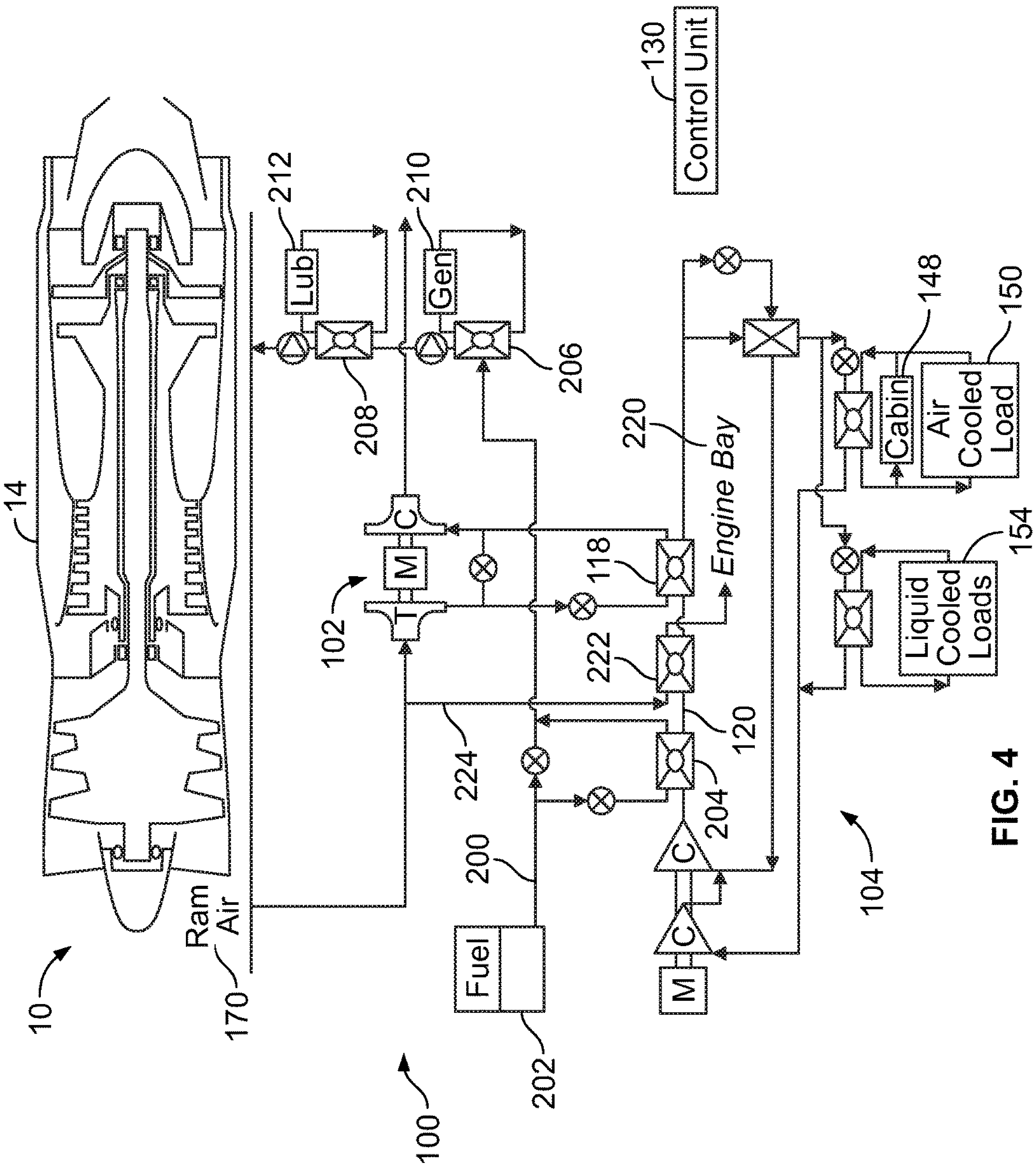
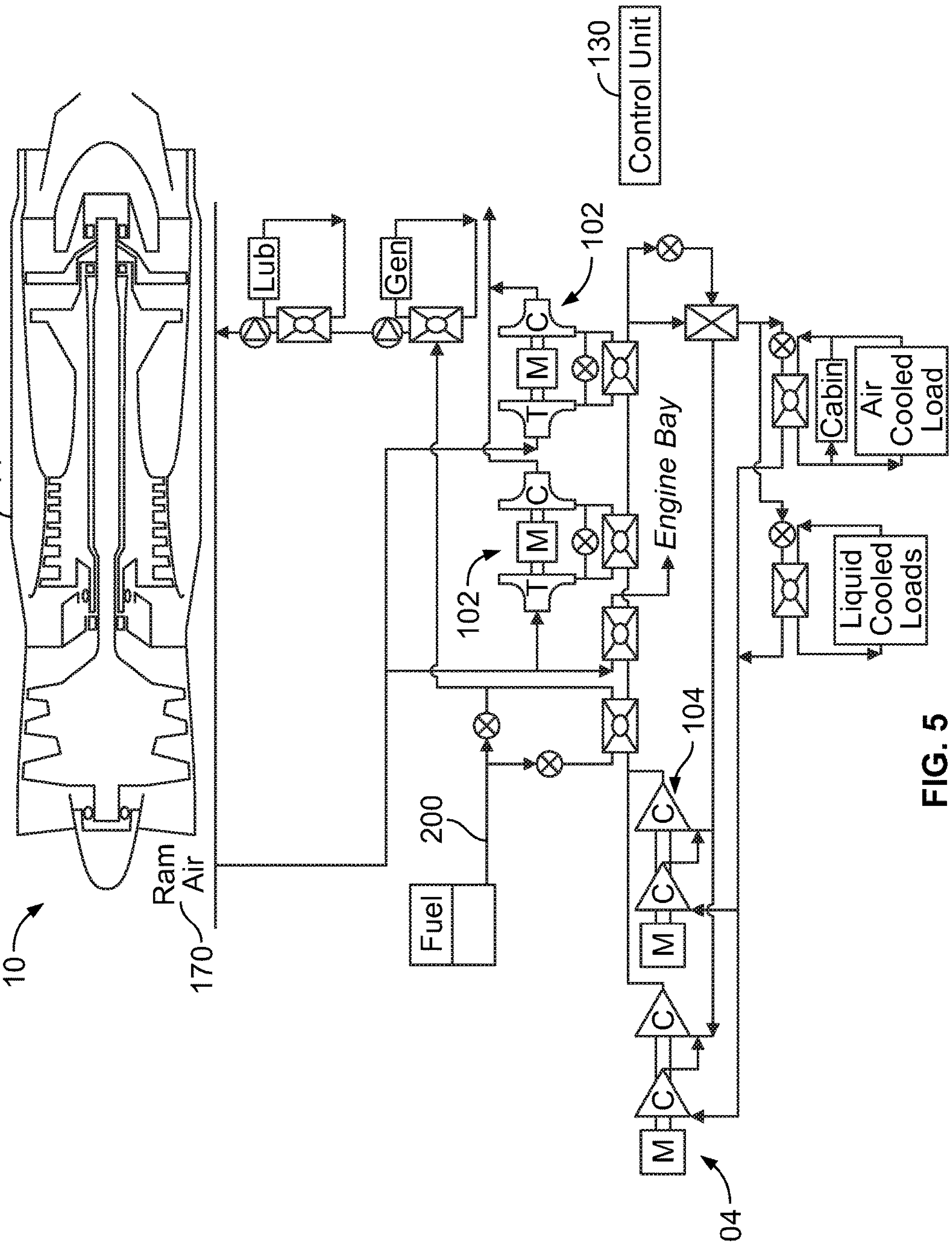

10
14
Ram Air
170
100
Fuel
202
200
224
102
T
M
C
208
212
Lub
210
Gen
206
220
Engine Bay
118
222
120
204
104
M
C
C
130
Control Unit
148
Cabin
150
Air Cooled Load
154
Liquid Cooled Loads

FIG. 4



10
14
Ram Air
170
Lub
Gen
102
102
130
Control Unit
T
M
C
Engine Bay
Cabin
Air Cooled Load
Liquid Cooled Loads
Fuel
200
104
104
M
C

FIG. 5

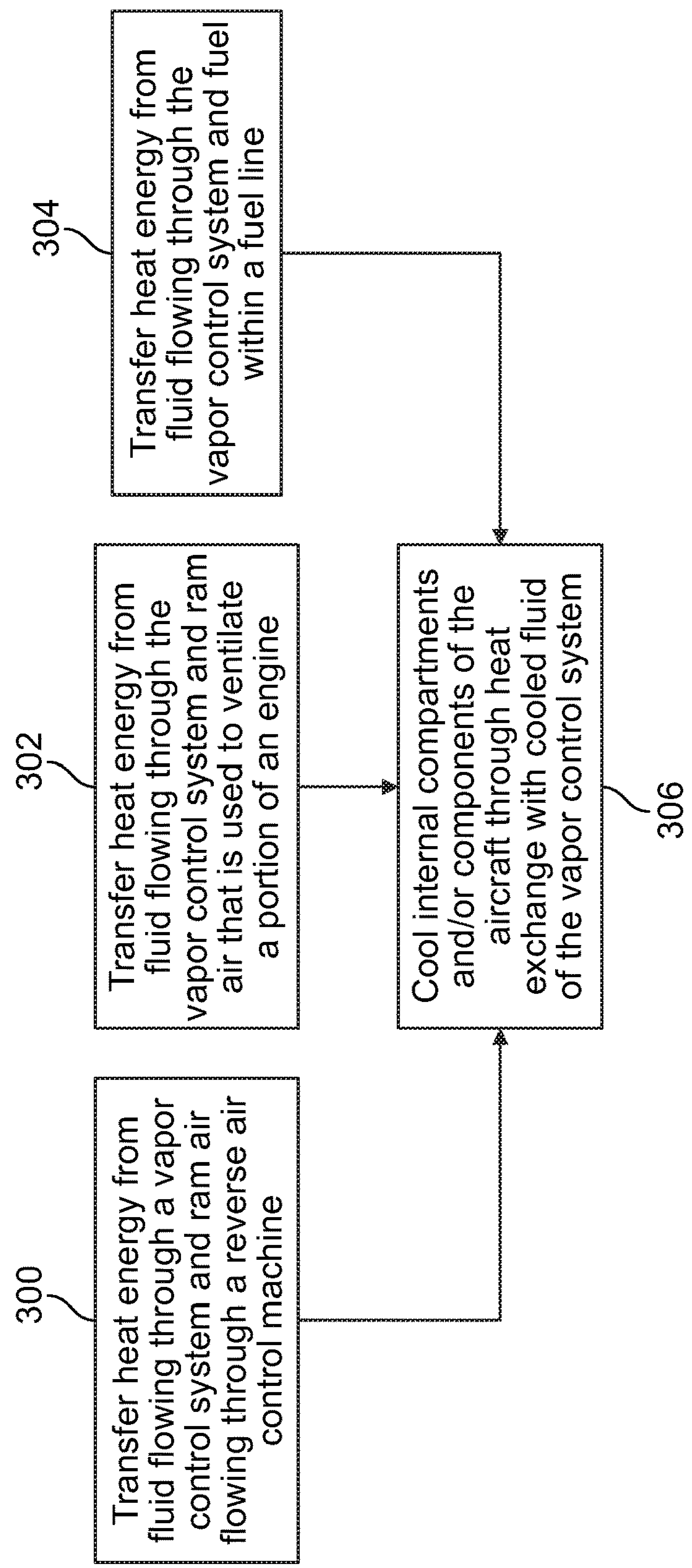

300
Transfer heat energy from fluid flowing through a vapor control system and ram air flowing through a reverse air control machine
302
Transfer heat energy from fluid flowing through the vapor control system and ram air that is used to ventilate a portion of an engine
304
Transfer heat energy from fluid flowing through the vapor control system and fuel within a fuel line
306
Cool internal compartments and/or components of the aircraft through heat exchange with cooled fluid of the vapor control system

FIG. 6

THERMAL MANAGEMENT SYSTEMS AND METHODS

FIELD OF THE DISCLOSURE

Embodiments of the present disclosure generally relate to thermal management systems and methods, and, more particularly, to thermal management systems and methods that are configured to efficiently condition portions of an aircraft, such as an internal cabin, electronic components, and the like.

BACKGROUND OF THE DISCLOSURE

Various aircraft draw air from turbine compression systems of one or more engines in order to maintain cabin pressure and to power auxiliary systems. The drawn air from the engine(s) is bleed air. In general, bleed air is compressed air that is drawn from a compressor stage of an engine, which is typically upstream from fuel-burning portions of the engine.

Known aircraft include systems that route bleed air through air conditioning systems to cool sub-systems within the aircraft, as well as internal chambers, such as the cockpit and the cabin. However, utilizing bleed air in relation to air conditioning within an aircraft decreases engine efficiency and aircraft range because energy is expended compressing the air, which is subsequently decompressed and re-cooled when used for air conditioning.

Air cycle machines have been used to provide air conditioning for various commercial and military aircraft. A typical air cycle machine utilizes high temperature, high pressure bleed air extracted from the compressor of a main engine, for example. As noted, however, extraction of bleed air expends energy, which is generated through fuel consumption. In short, a portion of the fuel is used to extract the bleed air, which, in turn, reduces the operating range of an aircraft. Further, aircraft range is typically further reduced because a typical air cycle machine has a low coefficient of performance (COP), which may be further reduced as the speed of the aircraft increases.

SUMMARY OF THE DISCLOSURE

A need exists for a system and method of efficiently and conditioning an internal chamber and/or components of an aircraft.

With that need in mind, certain embodiments of the present disclosure provide a thermal management system that is configured to cool portions of a vehicle. The thermal management system may include at least one vapor control system (VCS) that is configured to cool the portions of the vehicle. The VCS circulates a fluid therethrough to cool the portions of the vehicle through heat exchange. At least one reverse air cycle machine (RACM) couples to the VCS through a first heat exchanger. The RACM is configured to receive ram air. The RACM expands the ram air. Heat from the fluid circulating through the at least one VCS is transferred to the expanded ram air through the first heat exchanger. The thermal management system may refrain from utilizing bleed air from an engine of the vehicle.

The RACM may include a turbine. The ram air may at least partially power the turbine. The RACM may include a compressor that compresses the ram air after the heat from the fluid is transferred to the ram air. The ram air is exhausted from the vehicle after the compressor compresses the ram air.

The thermal management system may also include a second heat exchanger that couples the VCS to a ram air conduit that connects to a ram air inlet. Heat from the fluid circulating through the VCS is also transferred to the ram air flowing through the ram air conduit through the second heat exchanger.

The thermal management system may also include a third heat exchanger that couples the VCS to a fuel line that connects a fuel tank to an engine of the vehicle. Heat from the fluid circulating through the VCS is also transferred to fuel flowing through the fuel line through the third heat exchanger.

In at least one embodiment, the at least two parallel VCS may be used. In at least one embodiment, the at least two parallel RACMs may be used.

The RACM may include one or more first valves configured to control a flow of ram air through a heat exchange circuit that includes the first exchanger. The VCS may include one or more second valves configured to control a flow of the fluid through the VCS. The thermal management system may also include a control unit operatively coupled to the first valve(s) and the second valve(s). The control unit selectively controls the one or first valve(s) and the second valve(s).

Certain embodiments of the present disclosure provide a thermal management method of cooling portions of a vehicle. The thermal management method may include cooling the portions of the vehicle with at least one vapor control system (VCS). The cooling operation may include circulating a fluid the VCS to cool the portions of the vehicle through heat exchange. The method may also include receiving ram air with at least one reverse air cycle machine (RACM) that couples to the VCS through a first heat exchanger, expanding and cooling the ram air with the RACM, and transferring heat from the fluid circulating through the VCS to the ram air that is expanded through the first heat exchanger.

Certain embodiments of the present disclosure provide an aircraft that may include a fuselage defining one or more internal compartments, one or more electronic components, wings extending from the fuselage, an empennage extending from the fuselage, one or more engines, a fuel line that connects a fuel tank to an engine of the vehicle, and a thermal management system that cools portions of the aircraft without using bleed air from the one or more engines.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a perspective top view of an aircraft, according to an embodiment of the present disclosure.

FIG. **2**A illustrates a top plan view of an internal cabin of an aircraft, according to an embodiment of the present disclosure.

FIG. **2**B illustrates a top plan view of an internal cabin of an aircraft, according to an embodiment of the present disclosure.

FIG. **3** illustrates a schematic view of a thermal management system of an aircraft, according to an embodiment of the present disclosure.

FIG. **4** illustrates a schematic view of a thermal management system, according to an embodiment of the present disclosure.

FIG. **5** illustrates a schematic view of a thermal management system, according to an embodiment of the present disclosure.

FIG. **6** illustrates a flow chart of a method of conditioning portions of a vehicle, according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

The foregoing summary, as well as the following detailed description of certain embodiments will be better understood when read in conjunction with the appended drawings. As used herein, an element or step recited in the singular and preceded by the word "a" or "an" should be understood as not necessarily excluding the plural of the elements or steps. Further, references to "one embodiment" are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, embodiments "comprising" or "having" an element or a plurality of elements having a particular condition may include additional elements not having that condition.

Embodiments of the present disclosure provide systems and methods of efficiently cooling aircraft systems (for example, avionics systems), internal chambers, and the like. As such, embodiments of the present disclosure increase aircraft range (such as by consuming less fuel than known systems and methods). It has been found that embodiments of the present disclosure increase aircraft range, as compared to aircraft that utilize conventional bleed air thermal management systems, by a factor of four or more.

Certain embodiments of the present disclosure provide a thermal management system for an aircraft. The thermal management system may be used to cool aircraft systems and internal chambers, such as a cabin and cockpit. The thermal management system may include a reverse air cycle machine (RACM) coupled to a vapor control system (VCS). Heat energy is transferred between fluid flowing through the VCS and airflow from the RACM.

In at least one embodiment, ram air is routed to the RACM. The ram air may power the RACM, such as by turning a turbine of the RACM. The ram air flowing through the turbine is cooled by expansion. The cooled ram air is then passed through a heat exchanger that couples the VCS to the RACM, where the cooled ram air absorbs heat energy from fluid flowing through the VCS. After passing through the heat exchanger, the ram air is routed back to a compressor of the RACM, and then expelled from the aircraft.

Certain embodiments of the present disclosure provide a thermal management system that is used to cool aircraft systems and compartments. The thermal management system may include a ram air inlet, and a first conduit that delivers ram air from the inlet to a turbine of a RACM, which may be powered, at least in part, by ram air flowing through the turbine. A second conduit delivers the ram air, which has been cooled via expansion, from the turbine of the RACM to a heat exchanger coupled with a two stage VCS. A third conduit delivers the ram air from the heat exchanger to a compressor of the RACM. Ram air from the compressor of the RACM is expelled from the aircraft through an outlet. One or more valves may be used to control the volume of air flow through the heat exchanger and through the system.

The thermal management system may be bleedless, in that it does not utilize bleed air from an engine. The thermal management system combines a Vapor Cycle System (VCS) with a Reverse Air Control Machine (RACM). The VCS conditions aircraft heat loads. A subcooler may be employed in the VCS to further improve cycle performance. Two stages of refrigeration compression may be employed to increase refrigerant condensing temperature. The RACM may be used to generate a cold heat sink for the VCS by expanding ram air. After absorbing waste heat, the expanded ram air may be compressed and dumped overboard. By lowering the temperature of the ram air through expansion, the RACM reduces the amount of ram air used, which reduces ram drag and improves vehicle performance. The thermal management system may also utilize fuel and unexpanded ram air as additional heat sinks. Pressurized ram air may be used to drive the RACM, at least in part. In at least one embodiment, the RACM may also include an electric motor that assists the RACM in expanding and compressing the ram air.

To maintain high efficiency, parallel vapor cycle compression and/or multiple RACM units may be used. In addition to improving efficiency, parallel units reduce the size of turbo machinery of the aircraft.

FIG. **1** illustrates a perspective top view of a vehicle, such as an aircraft **10** (or aircraft assembly), according to an embodiment of the present disclosure. The aircraft **10** may include a propulsion system **12** that may include two turbofan engines **14**, for example. Optionally, the propulsion system **12** may include more engines **14** than shown. The engines **14** are carried by wings **16** of the aircraft **10**. In other embodiments, the engines **14** may be carried by a fuselage **18** and/or an empennage **20**. The empennage **20** may also support horizontal stabilizers **22** and a vertical stabilizer **24**.

The fuselage **18** of the aircraft **10** defines an internal cabin, which may include a cockpit, one or more work sections (for example, galleys, personnel carry-on baggage areas, and the like), one or more passenger sections (for example, first class, business class, and coach sections), and an aft section in which an aft rest area assembly may be positioned. Each of the sections may be separated by a cabin transition area, which may include one or more class divider assemblies. Overhead stowage bin assemblies may be positioned throughout the internal cabin.

As explained below, the aircraft **10** may include a thermal management system that is used to cool various systems within the aircraft, as well as the internal cabin. Alternatively, instead of an aircraft, embodiments of the present disclosure may be used with various other vehicles, such as automobiles, buses, locomotives and train cars, watercraft, and the like.

FIG. **2**A illustrates a top plan view of an internal cabin **30** of an aircraft, according to an embodiment of the present disclosure. The internal cabin **30** may be within a fuselage **32** of the aircraft. For example, one or more fuselage walls may define the internal cabin **30**. The internal cabin **30** includes multiple sections, including a front section **33**, a first class section **34** (or first class suites, cabins, for example), a business class section **36**, a front galley station **38**, an expanded economy or coach section **40**, a standard economy or coach section **42**, and an aft section **44**, which may include multiple lavatories and galley stations. It is to be understood that the internal cabin **30** may include more or less sections than shown. For example, the internal cabin **30** may not include a first class section, and may include more or less galley stations than shown. Each of the sections may be separated by a cabin transition area **46**, which may include class divider assemblies between aisles **48**.

As shown in FIG. **2**A, the internal cabin **30** includes two aisles **50** and **52** that lead to the aft section **44**. Optionally, the internal cabin **30** may have less or more aisles than shown. For example, the internal cabin **30** may include a single aisle that extends through the center of the internal cabin **30** that leads to the aft section **44**.

FIG. 2B illustrates a top plan view of an internal cabin **80** of an aircraft, according to an embodiment of the present disclosure. The internal cabin **80** may be within a fuselage **81** of the aircraft. For example, one or more fuselage walls may define the internal cabin **80**. The internal cabin **80** includes multiple sections, including a cockpit **89**, a main cabin **82** having passenger seats **83**, and an aft section **85** behind the main cabin **82**. It is to be understood that the internal cabin **80** may include more or less sections than shown.

The internal cabin **80** may include a single aisle **84** that leads to the aft section **85**. The single aisle **84** may extend through the center of the internal cabin **80** that leads to the aft section **85**. For example, the single aisle **84** may be coaxially aligned with a central longitudinal plane of the internal cabin **80**.

FIG. **3** illustrates a schematic view of a thermal management system **100** of the aircraft **10**, according to an embodiment of the present disclosure. The thermal management system **100** may include a reverse air cycle machine (RACM) **102** coupled to a vapor control system (VCS) **104**.

A ram air inlet **106** is formed through a portion of the aircraft **10**. For example, the ram air inlet **106** may be formed through a portion of the fuselage **18** (shown in FIG. **1**), the wings **16** (shown in FIG. **1**), and/or the like. Additional ram inlets **106** may be formed through the portion of the aircraft **10**.

The ram air inlet **106** is coupled to the RACM **102** through an inlet conduit **108**, such as a tube, pipe, plenum, or other such structure. The RACM **102** includes a turbine **110** coupled to a motor **112**. The RACM **102** also includes a compressor **114**. The RACM may provide a refrigeration unit for an environmental control system (ECS), such as the thermal management system **100**.

The RACM **102** may include or otherwise be coupled to a heat transfer circuit **115**. The heat transfer circuit **115** may include an exchange inlet conduit **116** that extends from the turbine **110** to an inlet of a heat exchanger **118** through the exchange inlet conduit **116**, and an exchange inlet conduit **120** of the VCS **104** pass. The heat exchanger **118** couples the RACM **102** to the VCS **104**. An exchange outlet conduit **122** extends from an outlet of the heat exchanger **118** to the compressor **114** of the RACM **114**. An outlet of the compressor **114** connects to an outlet conduit **124** that connects to an air outlet **126** formed through a portion of the aircraft **10**, such as a portion of the fuselage **18** (shown in FIG. **1**).

One or more valves **128** may be disposed within the heat transfer conduit **115**. The valves **128** may be selectively operated and controlled by a remote control unit **130**. The control unit **130** operates the valves **128** to control fluid flow through the heat transfer conduit **115**.

The VCS **104** may be configured to provide vapor-compression refrigeration, in which a refrigerant undergoes phase changes to condition an internal cabin and/or systems of the aircraft **10**. The VCS **104** circulates the refrigerant therethrough to cool portions of the aircraft **10** through heat exchange. The refrigerant provides a fluid that circulates through the VCS **104**, through various phases (for example, liquid and vapor phases), in order to cool an internal cabin and/or components of the aircraft **10**.

The VCS **104** may include a motor **132** coupled to compressors **134** and **136**. The compressor **136** is coupled to the exchange inlet conduit **120** that passes through the heat exchanger **118**. An exchange outlet conduit **138** extends from an outlet of the heat exchanger **118** to a heat exchanger **140**. A return conduit **142** extends between the heat exchanger **140** and the compressor **136**. A conditioning conduit **144** extends between the heat exchanger **140** and a heat exchanger **146** that couples to a heat transfer circuit **147** that is coupled to a cabin **148** and air cooled loads **150** (for example, one or more electronic systems of the aircraft **10** that are cooled through air circulation) within the aircraft **10**. The conditioning conduit **144** may also couple to a heat exchanger **152** that couples to a heat transfer circuit **157** that couples to liquid cooled loads **154** (for example, one or more electronic systems of the aircraft **10** that are cooled through liquid circulation). Return conduits **155** and **156** couple outlets of the heat exchangers **146** and **152**, respectively, to the compressor **134**.

As shown, one or more valves **160** may be disposed within the various conduits of the VCS **104**. The valves **160** may be selectively controlled by the control unit **130** to provide a desired amount of fluid (for example, refrigerant or other such coolant) flow through the VCS **104**.

In operation, ram air **170** passes into the ram air inlet **106** and into the turbine **110** through the inlet conduit **108**. Ram air is airflow created by movement of the aircraft **10**, as opposed to bleed air, which is generated by the engine **14**. That is, as the aircraft moves, air flow is created in relation to the movement, and is forced into the inlet conduit **108**. The thermal management system **100** utilizes the ram air **170**, but not bleed air, in order to cool the fluid within the VCS **104**, which is, in turn, used to cool internal compartments and/or components of the aircraft **10**.

The ram air **170** passes into the turbine **110** and powers the turbine **110**. That is, the flow of the ram air **170** through the turbine **110** causes the turbine **110** to move. The motor **112** may be used to assist movement of the turbine **110**. As the ram air **170** passes through the turbine **110**, the ram air **170** expands and cools. The expanded, cooled ram air **170** then passes into the heat exchanger **118**.

As the ram air **170** passes through the heat exchanger **118**, heat energy is transferred from the fluid within the VCS **104** passing through the exchange inlet conduit **120** to the ram air **170** through the heat exchanger **118**. As such, the RACM **102** provides a heat sink in which the ram air **170** absorbs heat from the fluid flowing through the VCS **104**. The ram air **170** then passes into the compressor **114** of the RACM **102**, where it is compressed, and then is exhausted out of the aircraft **10** through the air outlet **126**.

The fluid flowing through the VCS **104** is cooled through energy exchange with the ram air **170**. The cooled fluid within the VCS **104** is used to pick up heat from the cabin **148**, the air cooled load **150**, and the liquid cooled loads **154** through energy exchange, thereby cooling the cabin **148**, the air cooled load **150**, and the liquid cooled loads.

The control unit **130** may operate to selectively control fluid flow through the thermal management system **100** through the valves **128** and **160**. For example, the control unit **130** may selectively open and close the valves **128** and **160** to control a temperature of the fluids (whether gas, vapor, or liquid) through the various conduits, in order to control temperatures of the cabin **148**, the air cooled load **150**, and the liquid cooled loads **154**.

As used herein, the term “control unit,” “unit,” “central processing unit,” “CPU,” “computer,” or the like may include any processor-based or microprocessor-based system including systems using microcontrollers, reduced instruction set computers (RISC), application specific integrated circuits (ASICs), logic circuits, and any other circuit or processor including hardware, software, or a combination thereof capable of executing the functions described herein. Such are exemplary only, and are thus not intended to limit in any way the definition and/or meaning of such terms. For example, the control unit **130** may be or include one or more processors that are configured to control operation of the thermal management system **100**.

The control unit **130** is configured to execute a set of instructions that are stored in one or more storage elements (such as one or more memories), in order to process data. For example, the control unit **130** may include or be coupled to one or more memories. The storage elements may also store data or other information as desired or needed. The storage elements may be in the form of an information source or a physical memory element within a processing machine.

The set of instructions may include various commands that instruct the control unit **130** as a processing machine to perform specific operations such as the methods and processes of the various embodiments of the subject matter described herein. The set of instructions may be in the form of a software program. The software may be in various forms such as system software or application software. Further, the software may be in the form of a collection of separate programs, a program subset within a larger program or a portion of a program. The software may also include modular programming in the form of object-oriented programming. The processing of input data by the processing machine may be in response to user commands, or in response to results of previous processing, or in response to a request made by another processing machine.

The diagrams of embodiments herein may illustrate one or more control or processing units, such as the control unit **130**. It is to be understood that the processing or control units may represent circuits, circuitry, or portions thereof that may be implemented as hardware with associated instructions (e.g., software stored on a tangible and non-transitory computer readable storage medium, such as a computer hard drive, ROM, RAM, or the like) that perform the operations described herein. The hardware may include state machine circuitry hardwired to perform the functions described herein. Optionally, the hardware may include electronic circuits that include and/or are connected to one or more logic-based devices, such as microprocessors, processors, controllers, or the like. Optionally, the control unit **130** may represent processing circuitry such as one or more of a field programmable gate array (FPGA), application specific integrated circuit (ASIC), microprocessor(s), and/or the like. The circuits in various embodiments may be configured to execute one or more algorithms to perform functions described herein. The one or more algorithms may include aspects of embodiments disclosed herein, whether or not expressly identified in a flowchart or a method.

As used herein, the terms "software" and "firmware" are interchangeable, and include any computer program stored in memory for execution by a computer, including RAM memory, ROM memory, EPROM memory, EEPROM memory, and non-volatile RAM (NVRAM) memory. The above memory types are exemplary only, and are thus not limiting as to the types of memory usable for storage of a computer program.

FIG. **4** illustrates a schematic view of the thermal management system **100**, according to an embodiment of the present disclosure. The thermal management system **100** is similar to the embodiment shown in FIG. **4**. In addition to the expanded ram air flowing through the RACM **102** being a heat sink in relation to the fluid flowing through the VCS **104**, a fuel line **200** also provides an additional heat sink. The fuel line **200** provides a fuel delivery conduit between a fuel tank **202** and the engine **14**. A heat exchanger **204** couples the fuel line **200** to the exchange inlet conduit **120** of the VCS **104**. As such, the heat exchanger **204** transfers heat energy from the fluid within the exchange inlet conduit **120** to the fuel within the fuel line **200**, thereby increasing the temperature of the fuel, and decreasing the temperature of the fluid within the exchange inlet conduit **120**.

The fuel line **200** may then pass through heat exchangers **206** and **208** of an engine generator **210** and a lubrication system **212**. Heat energy is transferred from the generator **210** and the lubrication system **212** to fuel within the fuel line **200** by way of the heat exchangers **206** and **208**, thereby increasing the temperature of the fuel, and decreasing the temperature of the generator **210** and the lubrication system **212**. The fuel is then delivered to the engine through the fuel line **200**.

Alternatively, the fuel line **200** may not be coupled to the generator **210** and the lubrication system **212** through the heat exchangers **206** and **208**. Instead, fuel within the fuel line **200** may receive heat energy from the VCS **104** by way of the heat exchanger **204**, and then pass directly to the engine **14**.

Additionally, ram air **170** (which is not expanded and cooled) that is used to ventilate an engine bay **220** may be used as an additional heat sink. A first portion of the ram air **170** may be delivered to the RACM **102**, as described above. A second portion of the ram air **170** may be delivered to a heat exchanger **222** coupled to the exchange inlet conduit **120** by way of a transfer conduit **224**. The ram air **170** passing through the heat exchanger **222** receives heat energy from the fluid (for example, refrigerant or other coolant) flowing through the heat exchanger **222**. As such, the temperature of the ram air **170** passing through the heat exchanger **222** increases, which reduces the temperature of the fluid flowing through the exchange inlet conduit **120**. The ram air **170** then passes to the engine bay **220**.

Accordingly, the thermal management system **100** provides three heat sinks. First, the RACM **102** provides a heat sink that receives heat energy from the VCS **104** through the heat exchanger **118**. Second, the fuel line **200** provides a heat sink that receives heat energy from the VCS **104** through the heat exchanger **204**. Third, the ram air **170** provides a heat sink that receives heat energy from the VCS **104** through the heat exchanger **222**. All three heat sinks absorb heat energy from the VCS **104**, thereby cooling the fluid flowing through the VCS **104**, which thereby efficiently cools the cabin **148** and various components of the aircraft **10**, such as those that are cooled through air circulation or ventilation and those that are cooled through liquid circulation.

FIG. **5** illustrates a schematic view of the thermal management system **100**, according to an embodiment of the present disclosure. The thermal management system **100** shown in FIG. **5** is similar to the thermal management system described with respect to FIG. **4**, except that the thermal management system **100** may include two RACMs **102** and two VCS **104**. The RACMs **102** are connected in parallel, while the VCS **104** are also connected in parallel. The multiple RACMs **102** and VCS **104** provide increased energy exchange with portions of the aircraft **10**. The multiple RACMs **102** and VCS **104** provide increased and efficient conditioning of the portions of the aircraft **10** (such as the cabin and liquid and air cooled components of the aircraft **10**) over a wide cooling load range. For example, the additional RACM **104** and the additional VCS **104** provide increased cooling capacity for the aircraft **10**.

Alternatively, the thermal management system **100** may include more or less RACMs **102** and VCS **104** than shown. For example, the thermal management system may include three or more RACMs **102** and three or more VCS **104**. In at least one other embodiment, the thermal management system **100** may include two or more RACMs **102** and one VCS **104**. In at least one other embodiment, the thermal management system **100** may include two or more VCS **104** and one RACM **102**.

FIG. **6** illustrates a flow chart of a method of conditioning portions of a vehicle, according to an embodiment of the present disclosure. The method begins at **300**, in which heat energy is transferred from fluid flowing through a VCS and ram air that flows through a RACM. At **302**, heat energy is transferred from fluid flowing the VCS and ram air that is used to ventilate a portion of an engine bay of the vehicle. At **304**, heat energy is transferred from fluid flowing through the VCS and fuel within a fuel line that powers the engine. **300**, **302**, and **304** may occur in series or in parallel. The ram air that flows through the RACM, the ram air that is used to ventilate the engine bay, and the fuel within the fuel line each provide a separate and distinct heat sink that absorbs heat energy from the fluid within the VCS, thereby reducing the temperature of the fluid within the VCS, which may then absorb an increased amount of heat energy from various compartments and/or components of the aircraft through heat exchange. At **306**, the internal compartments and/or components of the aircraft are cooled through heat exchange with the fluid of the VCS that has been cooled through the various heat sinks.

Alternatively, the method may not include **302**. Also, alternatively, the method may not include **304**.

Referring to FIGS. **1**-**6**, embodiments of the present disclosure provide thermal management systems that are configured to efficiently cool compartments and/or components of a vehicle (such as an aircraft) through transferring heat energy from fluid (such as coolant) within at least one VCS to ram air, such as may be used to ventilate an engine, and/or which has passed through at least one RACM. The thermal management systems may also transfer heat energy from the fluid within the one or more VCS to fuel within a fuel line of the vehicle. The thermal management systems do not utilize bleed air. As such, the thermal management systems do not expend fuel compressing bleed air, which thereby allows the fuel to be used by the engine(s), and therefore increase the fuel range of the vehicle.

While various spatial and directional terms, such as top, bottom, lower, mid, lateral, horizontal, vertical, front and the like may be used to describe embodiments of the present disclosure, it is understood that such terms are merely used with respect to the orientations shown in the drawings. The orientations may be inverted, rotated, or otherwise changed, such that an upper portion is a lower portion, and vice versa, horizontal becomes vertical, and the like.

As used herein, a structure, limitation, or element that is "configured to" perform a task or operation is particularly structurally formed, constructed, or adapted in a manner corresponding to the task or operation. For purposes of clarity and the avoidance of doubt, an object that is merely capable of being modified to perform the task or operation is not "configured to" perform the task or operation as used herein.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the various embodiments of the disclosure without departing from their scope. While the dimensions and types of materials described herein are intended to define the parameters of the various embodiments of the disclosure, the embodiments are by no means limiting and are exemplary embodiments. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the various embodiments of the disclosure should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. § 112(f), unless and until such claim limitations expressly use the phrase "means for" followed by a statement of function void of further structure.

This written description uses examples to disclose the various embodiments of the disclosure, including the best mode, and also to enable any person skilled in the art to practice the various embodiments of the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the various embodiments of the disclosure is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if the examples have structural elements that do not differ from the literal language of the claims, or if the examples include equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A thermal management system that is configured to cool portions of a vehicle, the thermal management system comprising:

at least one vapor control system (VCS) that is configured to cool the portions of the vehicle, wherein the at least one VCS circulates a refrigerant therethrough to cool the portions of the vehicle through heat exchange, wherein the at least one VCS comprises a VCS compressor that compresses the refrigerant;

at least one reverse air cycle machine (RACM) that couples to the at least one VCS through a first heat exchanger, wherein the at least one RACM is configured to receive ram air, wherein the at least one RACM expands the ram air, and wherein heat from the refrigerant circulating through the at least one VCS after being compressed by the VCS compressor is transferred to the ram air that is expanded through the first heat exchanger, wherein the at least one RACM comprises a RACM compressor and one or more RACM valves, the one or more RACM valves disposed within a heat transfer circuit that includes conduits connected to the first heat exchanger, wherein the RACM compressor compresses the ram air after the heat from the refrigerant is transferred to the ram air, and wherein the ram air is exhausted from the vehicle after the RACM compressor compresses the ram air, and

a control unit operatively coupled to the one or more RACM valves, wherein the control unit selectively operates the one or more RACM valves to control a flow of the ram air through the heat transfer circuit and the first heat exchanger for regulating a temperature of the portions of the vehicle that are cooled by the at least one VCS.

2. The thermal management system of claim 1, wherein the at least one RACM comprises a turbine, wherein the ram air at least partially powers the turbine.

3. The thermal management system of claim 1, wherein the thermal management system refrains from utilizing bleed air from an engine of the vehicle.

4. The thermal management system of claim 1, further comprising a second heat exchanger that couples the at least one VCS to a ram air conduit that connects to a ram air inlet, wherein heat from the refrigerant circulating through the at least one VCS is also transferred to the ram air flowing through the ram air conduit through the second heat exchanger.

5. The thermal management system of claim 1, further comprising a second heat exchanger that couples the at least one VCS to a fuel line that connects a fuel tank to an engine of the vehicle, wherein heat from the refrigerant circulating through the at least one VCS is also transferred to fuel flowing through the fuel line through the second heat exchanger.

6. The thermal management system of claim 1, wherein the at least one VCS comprises at least two parallel VCS.

7. The thermal management system of claim 1, wherein the at least one RACM comprises at least two parallel RACMs.

8. The thermal management system of claim 1, wherein the at least one VCS comprises one or more VCS valves, and the control unit is configured to selectively operate the one or more VCS valves to control a flow of the refrigerant through the at least one VCS.

9. A thermal management method of cooling portions of a vehicle, the thermal management method comprising:

cooling the portions of the vehicle with at least one vapor control system (VCS), wherein the cooling operation comprises circulating a refrigerant through the at least one VCS to cool the portions of the vehicle through heat exchange and compressing the refrigerant using a compressor of the at least one VCS;

receiving ram air with at least one reverse air cycle machine (RACM) that couples to the at least one VCS through a first heat exchanger, the at least one RACM including a compressor and one or more RACM valves, the one or more RACM valves disposed within a heat transfer circuit that includes conduits connected to the first heat exchanger;

expanding the ram air with the at least one RACM;

controlling a flow of the ram air, that is expanded, through the heat transfer circuit by selectively operating, via a control unit, the one or more RACM valves to regulate a temperature of the portions of the vehicle cooled by the at least one VCS;

transferring heat from the refrigerant circulating through the at least one VCS to the ram air, that is expanded, through the first heat exchanger;

using the compressor of the at least one RACM to compress the ram air after the heat from the compressed refrigerant is transferred to the ram air; and

exhausting the ram air from the vehicle after the compressor of the at least one RACM compresses the ram air.

10. The thermal management method of claim 9, further comprising at least partially powering a turbine of the at least one RACM with the received ram air.

11. The thermal management method of claim 9, further comprising using a second heat exchanger to transfer heat from the compressed refrigerant circulating through the at least one VCS to ram air within a conduit that connects to a ram air inlet.

12. The thermal management method of claim 9, further comprising using a second heat exchanger to transfer heat from the compressed refrigerant circulating through the at least one VCS to fuel flowing through a fuel line.

13. The thermal management method of claim 9, further comprising:

controlling a flow of the refrigerant through the at least one VCS by selectively operating, via the control unit, one or more VCS valves.

14. An aircraft comprising:

a fuselage defining one or more internal compartments;

wings extending from the fuselage;

an empennage extending from the fuselage;

one or more engines secured to one or more of the wings, the fuselage, or the empennage;

a fuel line that connects a fuel tank to an engine of the aircraft;

one or more electronic sub-systems; and

a thermal management system that cools a cabin or a load of the aircraft without using bleed air from the one or more engines, the thermal management system comprising:

at least one vapor control system (VCS) that circulates a refrigerant therethrough to cool the cabin or the load of the aircraft through heat exchange, wherein the at least one VCS comprises a VCS compressor that compresses the refrigerant;

at least one reverse air cycle machine (RACM) that couples to the at least one VCS through a first heat exchanger, wherein the at least one RACM receives ram air generated by motion of the aircraft, wherein the at least one RACM comprises a turbine, a RACM compressor, and one or more RACM valves, the one or more RACM valves disposed within a heat transfer circuit that includes conduits connected to the first heat exchanger, wherein the turbine expands the ram air and is at least partially powered by the ram air, and wherein heat from the refrigerant circulating through the at least one VCS is transferred within the first heat exchanger to the ram air that is expanded, wherein the RACM compressor compresses the ram air after the heat from the refrigerant is transferred to the ram air, and wherein the ram air is exhausted from the aircraft after the RACM compressor compresses the ram air;

a second heat exchanger that couples the at least one VCS to a ram air conduit that connects to a ram air inlet, wherein heat from the refrigerant circulating through the at least one VCS is transferred within the second heat exchanger to the ram air flowing through the ram air conduit;

a third heat exchanger that couples the at least one VCS to the fuel line, wherein heat from the refrigerant circulating through the at least one VCS is transferred within the third heat exchanger to fuel flowing through the fuel line; and

a control unit operatively coupled to the one or more RACM valves and configured to selectively operate the one or more RACM valves to control a flow of the ram air through the heat transfer circuit and the first heat exchanger for regulating a temperature of the cabin or the load of the vehicle that is cooled by the at least one VCS.

15. The thermal management system of claim **14**, wherein the at least one VCS comprises at least two parallel VCS, and wherein the at least one RACM comprises at least two parallel RACMs.

16. The thermal management system of claim **14**, wherein the at least one VCS comprises one or more VCS valves configured to control a flow of the refrigerant through the at least one VCS, wherein the control unit is operatively coupled to the one or more VCS valves and selectively operates the one or more VCS valves.

17. The thermal management system of claim **1**, further comprising a second heat exchanger along the at least one VCS downstream of the first heat exchanger and upstream of the VCS compressor, wherein the refrigerant circulating through the at least one VCS absorbs heat within the second heat exchanger from a fluid of a second heat transfer circuit that provides cooling for at least one of a cabin or a load of the vehicle.

18. The thermal management system of claim **1**, wherein the VCS compressor is coupled to a motor that powers the VCS compressor.

19. The thermal management system of claim **1**, wherein at least some of the refrigerant condenses from a vapor to a liquid within the first heat exchanger upon transferring heat to the ram air.

20. The thermal management system of claim **2**, wherein the turbine and the RACM compressor are coupled to a common shaft and a motor is operatively connected to the turbine to selectively assist the ram air with powering the turbine.

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